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EFFECTS OF RETROROCKET EXHAUST ON DRAG OF 120° CONE AT SUBSONIC SPEEDS

by Edwin E. Davenport and Edwin E. Lee, Jr.

Langley Research Center
Hampton, Va. 23365

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16. Abstract

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SUMMARY

An investigation has been made in the Langley 16-foot transonic tunnel of a series of blunted cones equipped with simulated retrothrust nozzles. Three retrorocket configurations (4, 8, and 12 jets) which would be possible planetary entry candidates were tested at an angle of attack of 0° at Mach numbers of 0.30, 0.40, and 0.50. The results showed considerable interaction between retrothrust exhaust and aerodynamic drag. It would appear advantageous to jettison the front cone face when ablation requirements had been fulfilled.

INTRODUCTION

Exploration of the planets, such as the proposed exploration of Mars through the Viking Project, will eventually require soft landing of payloads on the surfaces of the planets. The use of retrothrust rockets is currently being considered as a method of final deceleration to provide impact velocities sufficiently low to insure survival of the payloads. Only meager information exists concerning the interaction of retrothrust exhaust on aerodynamic drag for high-drag shapes such as those currently being considered for planetary entry. Selecting a suitable configuration for a planetary entry space vehicle has been the subject of several studies such as those reported in references 1 and 2. The proposal of reference 1 indicates a preference for four retrorockets and a high-drag initial deceleration stage or aeroshell which would be jettisoned prior to final retrofire. The proposal of reference 2 indicates a preference for four retrorockets. As indicated in reference 3, a recent Viking proposal considers the use of only three retrorockets. Investigations such as those mentioned in references 4 and 5 have explored some of the effects of retrorocket exhaust on the aerodynamic characteristics of representative planetary entry vehicles.

The present investigation explored the possibilities of using 4, 8, or 12 retrorockets with a high-drag 120° conical aeroshell that would not be jettisoned prior to final retrofire. The models were built with interchangeable 120° face cones which incorporated simulated retrothrust nozzles and a common air plenum which supplied the high-pressure air which

was used to simulate the retrorocket exhaust. The cool-jet exhaust was operated at ratios of jet thrust to aerodynamic drag T/D_o up to about 9.0. Tests were made in air at Mach numbers of 0.30, 0.40, and 0.50 at 0^o incidence. These Mach numbers are believed to span the range of Mach numbers at which retrorocket deceleration would be initiated.

SYMBOLS

Measurements for this investigation are given in the International System of Units (SI). Details concerning the use of SI, together with physical constants and conversion factors, are given in reference 6.

A_{exit}	nozzle area at nozzle exit, meters^2
C_D	drag coefficient, $\frac{F_A - T}{qS}$
C_p	pressure coefficient, $\frac{p_l - p_\infty}{q}$
D_o	aerodynamic drag with jets off, newtons
$D_{jet\ on}$	aerodynamic drag with jet on, newtons
F_A	total axial force, $T + D_{jet\ on}$, newtons
M	Mach number
p	pressure, newtons/meter^2
q	free-stream dynamic pressure, newtons/meter^2
R	maximum radius of body, centimeters
S	reference area, πR^2, 0.0730 meter^2
T	corrected component of retrojet thrust in drag direction, newtons
y	radial coordinate, meters

Subscripts:

a	atmospheric

b conditions of base of body

j jet

l local

t total

∞ free stream

APPARATUS

Wind Tunnel

The tests were made in the Langley 16-foot transonic tunnel, which is a continuous-flow, single-return, atmospheric tunnel with a slotted octagonal throat. The test medium is air with provision for cooling. A more detailed description of this tunnel can be found in reference 7.

Model and Support System

Photographs of the model showing some of the model details are shown in figure 1. The three 120° cone configurations had 4, 8, or 12 nozzles. These nozzle configurations (including pressure orifice locations in the face cones) are shown in figure 2(a). Ratio of total nozzle exit area to maximum model cross-sectional area was held constant and the nozzle contour details are shown in figure 2(b). The nozzle face plates, machined from solid stainless steel were interchangeable on a common aft plenum chamber section as shown in figure 2(c). Details of these plates with some balance details and base-pressure orifice locations are also shown in the figure. The balance was a single-component (axial-force) balance which was designed to permit high-pressure air to pass through it directly into the plenum chamber. An overall assembly view of the model, sting, and sting support is shown as figure 2(d).

Air Supply for Rocket Simulation

The high-pressure air which was used to simulate retrorocket exhaust was obtained from a 34.47-MN/m^2 supply which was expanded to a lower pressure and heated by passing through a steam heat exchanger. The air was held to a fairly constant temperature corresponding to tunnel ambient temperature so that thermal reactions of a hot jet exhaust were not involved.

TESTS AND CORRECTIONS

The test conditions for the three Mach numbers at an angle of attack of 0° are shown in the following table $\left(p_{t,j}\right.$ taken equal to chamber pressure$\left.\right)$:

Mach number	q, N/m^2	$p_{t,j}/p_{\infty}$
0.30	5 860.5 to 6 136.3	0 to ≈62
.40	9 445.8 to 10 342.1	0 to ≈65
.50	14 410.0 to 14 961.6	0 to ≈69

Air temperature in the model plenum chamber was allowed to stabilize briefly before each data point was taken. A static calibration of the three model configurations was made before making tunnel runs.

The test conditions produced maximum approximate ratios of axial force (jet on) to axial force (jet off) as shown below:

Mach number	$(F_A)_{jet\ on}/(F_A)_{jet\ off}$ for model with –		
	4 jets	8 jets	12 jets
0.30	10.0	9.0	9.0
.40	6.0	5.0	5.0
.50	4.0	3.5	3.6

Retrojet thrust for the test points was calculated by using the measured chamber pressure and static calibration data and correcting for the ambient pressure of the wind-tunnel airstream. This corrected thrust was obtained from the following expression:

$$T = \text{Measured static thrust} + \left[(p_a - p_{\infty})A_{exit}\right]\cos 30^{\circ}$$

RESULTS AND DISCUSSION

The results of this investigation were obtained from pressure orifice readings from the model face and base and from axial-force balance readings. The static-thrust characteristics of the three nozzle configurations are presented in figure 3. The thrust was nondimensionalized by dividing by the jet-off drag and the jet total pressure was nondimensionalized by dividing by the tunnel free-stream static pressure corresponding to the three test Mach numbers. The curves are linear and independent of nozzle configuration.

Pressure Distributions

Pressure distributions over the front face of the cones, shown in figure 4, at all Mach numbers indicate a suction force (negative C_p) existing over a considerable part of the face when the jets are operating. This reduction in pressure would decrease the retroforce and helps to explain the unfavorable effect on aerodynamic drag for retrojet-on conditions shown in subsequent figures. A similar reduction, as noted in reference 8, was found to exist for supersonic test conditions.

A limited amount of information on pressure distribution over the base of the model is shown in figure 5. The suction forces shown in this figure for all configurations and all test conditions would augment total braking force as retrothrust pressures are increased but these base forces tend to be offset by the induced suction forces on the cone front surface.

Force-Measurement Results

Drag in this investigation is obtained by subtracting the corrected retrojet thrust from the total axial force. The initial effect of retrojet thrust on drag coefficient is unfavorable for all three configurations at all three Mach number conditions, as shown in figure 6. The C_D loss for the 4-jet nozzle configuration is partially recovered as thrust increases for the lower two Mach number conditions. Both the 8- and 12-jet configurations suffered greater initial drag losses than the 4-jet configuration, and although the 12-jet model reached a lower value of C_D initially, it showed a greater rate of recovery than the 4-jet model. The 8-jet model showed slight signs of drag recovery at Mach 0.30 but the end point at Mach 0.50 indicated a suction or negative drag. Since the aerodynamic drag falls off very rapidly as retrothrust increases, it becomes rather obvious that it would be advantageous to use a configuration in which the nozzles were beneath the cone face and would not fire until the cone face had been jettisoned after completion of the ablation requirement. Then the retronozzles could be fired directly downward and thus utilize their full value; it would also eliminate the unfavorable suction effects shown in figure 4. It is reasonable to attribute this suction force to a fence effect of the jet plume which prevents airflow over the forward face and results in a recirculation area outboard of the jets. Thus, if the aeroshell is not jettisoned prior to retrofire, it would be advantageous to locate the retrorockets as close to the periphery of the aeroshell as possible. This effect of increased retroforce when the jets were located away from the axis of symmetry was noted in reference 9.

The total axial force F_A which is equal to the sum of aerodynamic drag and retrothrust has been normalized by the jet-off drag D_o and is shown as a function of the jet retrothrust to jet-off drag ratio T/D_o in figure 7. Aerodynamic drag, in addition to the

retrothrust, is again shown to be present for the 4-jet configuration for all Mach number conditions. (See fig. 7(a).) The 8-jet configuration has lost its aerodynamic drag at a T/D_o equal to about 5.0 for Mach 0.40 and at T/D_o equal to 3.5 for Mach 0.50, as can be seen in figure 7(b). The total axial force F_A for the 12-jet configuration is nearly pure retrojet force at lower values of T/D_o but makes some C_D recovery at higher values of T/D_o, as shown in figure 7(c).

A summary plot of total braking efficiency $F_A/(T + D_o)$ as a function of T/D_o is presented in figure 8. The 4-jet nozzle model showed no losses above T/D_o of about 6.0 where $F_A/(T + D_o) \approx 1$ at Mach 0.30. Above a T/D_o ratio of about 6.0, both the 8- and 12-retrojet models exhibit about the same total braking force at Mach 0.30. The effect of change in Mach number is considerably less for the 12-retrojet configuration. This configuration showed greater recovery in aerodynamic drag in an earlier figure.

A final consideration might be that the retroforce due to aerodynamic drag (if retrorocket interference could be avoided) which would be developed at the lower velocities during terminal phase of reentry would probably be a very small percentage of the total retrothrust during retrorocket firing.

SUMMARY OF RESULTS

An investigation of the effects of retrothrust and retrothrust jet configuration on the drag characteristics of a blunted 120° cone model has been conducted in the Langley 16-foot transonic tunnel. The results can be summarized as follows:

1. The retrothrust jets produced suction forces over a considerable portion of the cone front face with attendant loss in aerodynamic drag.

2. The 4-jet configuration suffered the least losses in drag.

3. The 12-jet configuration made some recovery in drag at the higher levels of retrothrust blowing.

4. Aerodynamic drag will probably be a small percentage of the total retrothrust for force during retrofire.

5. It would appear desirable to jettison the nose cone after completion of the ablation requirement.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., April 22, 1971.

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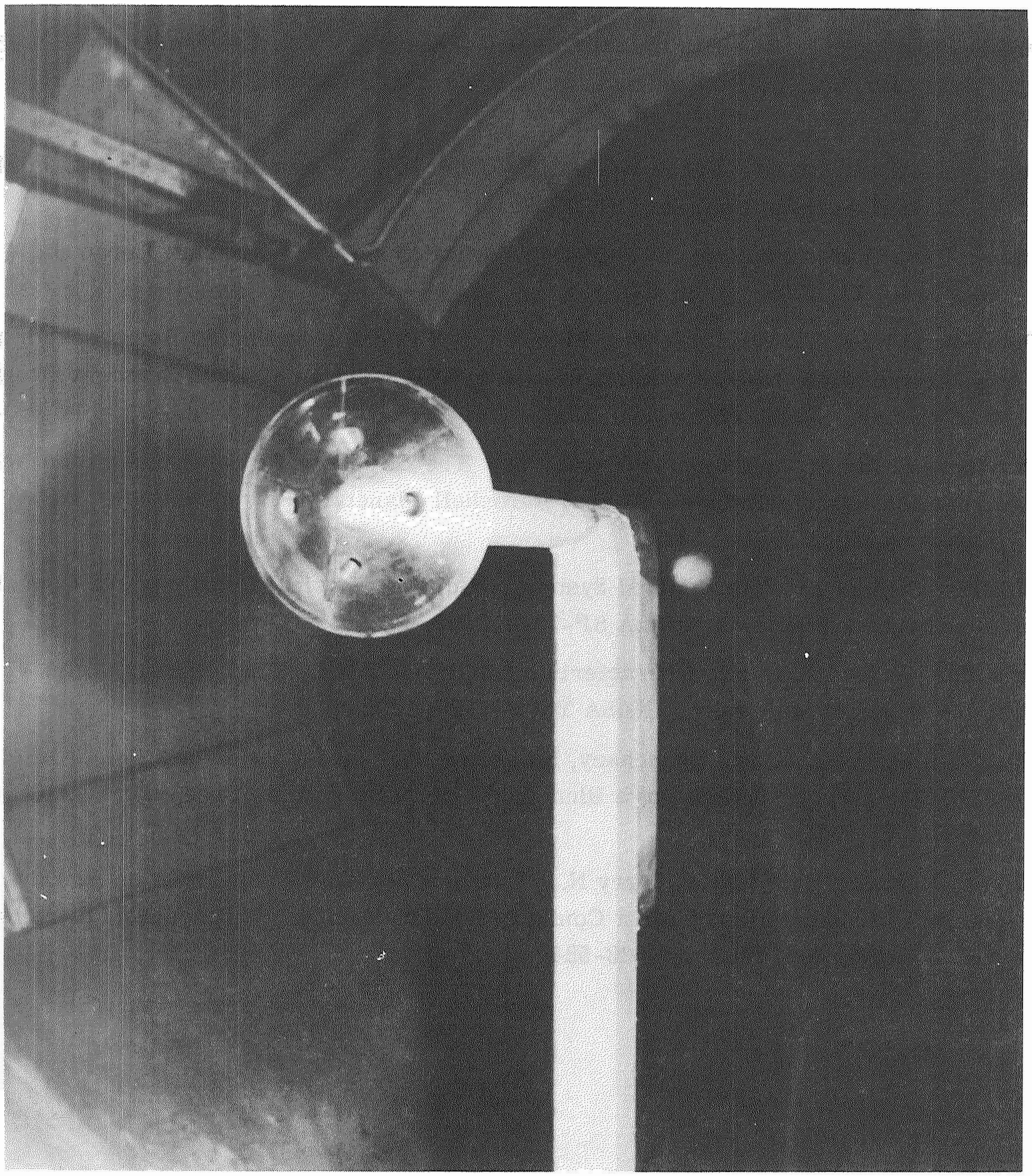
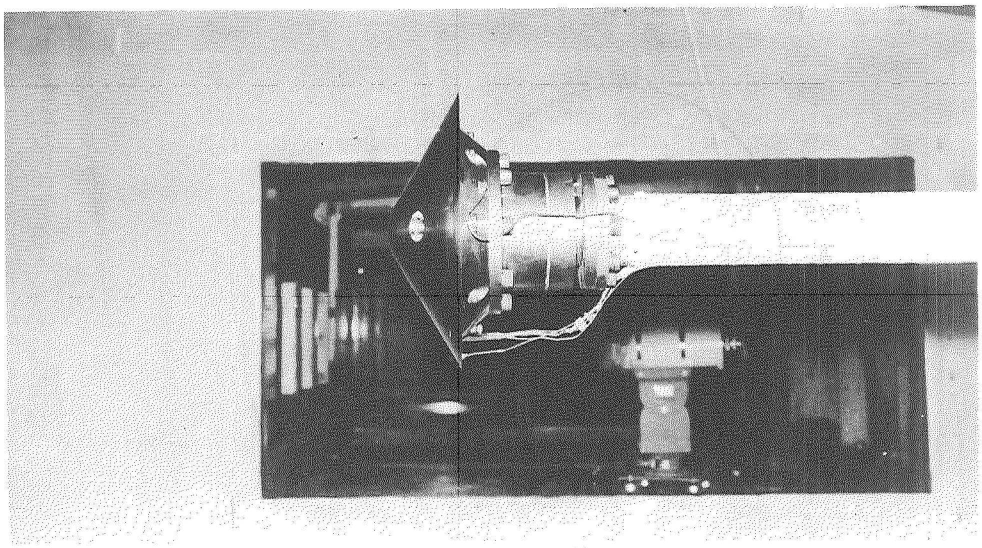
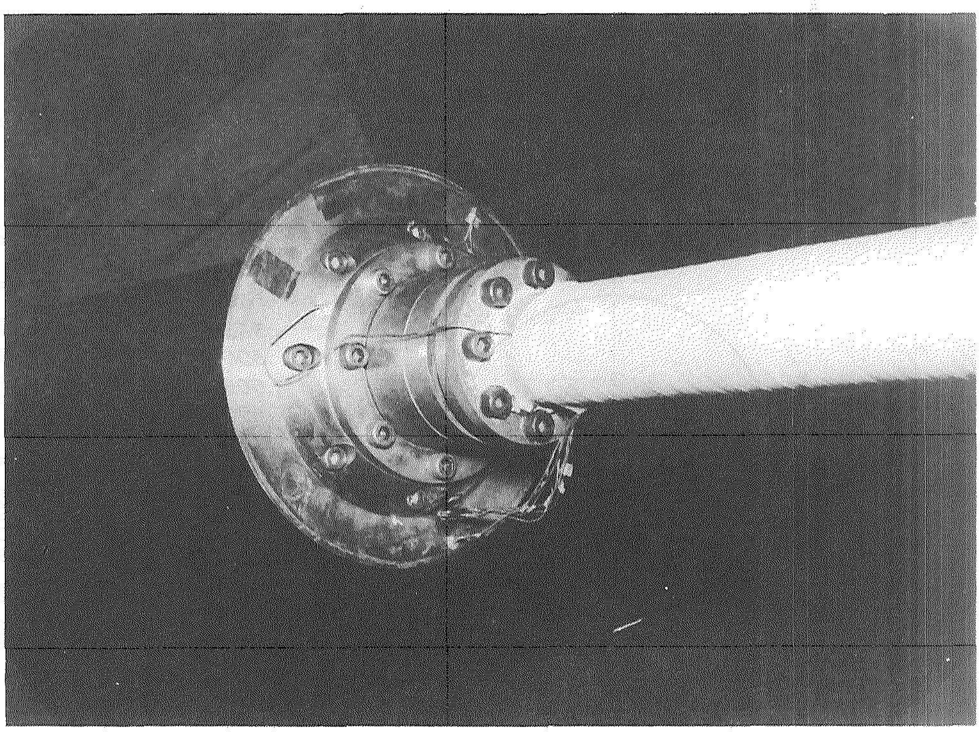


(a) Front view in Langley 16-foot tunnel. L-67-4336

Figure 1.- Photographs of model.

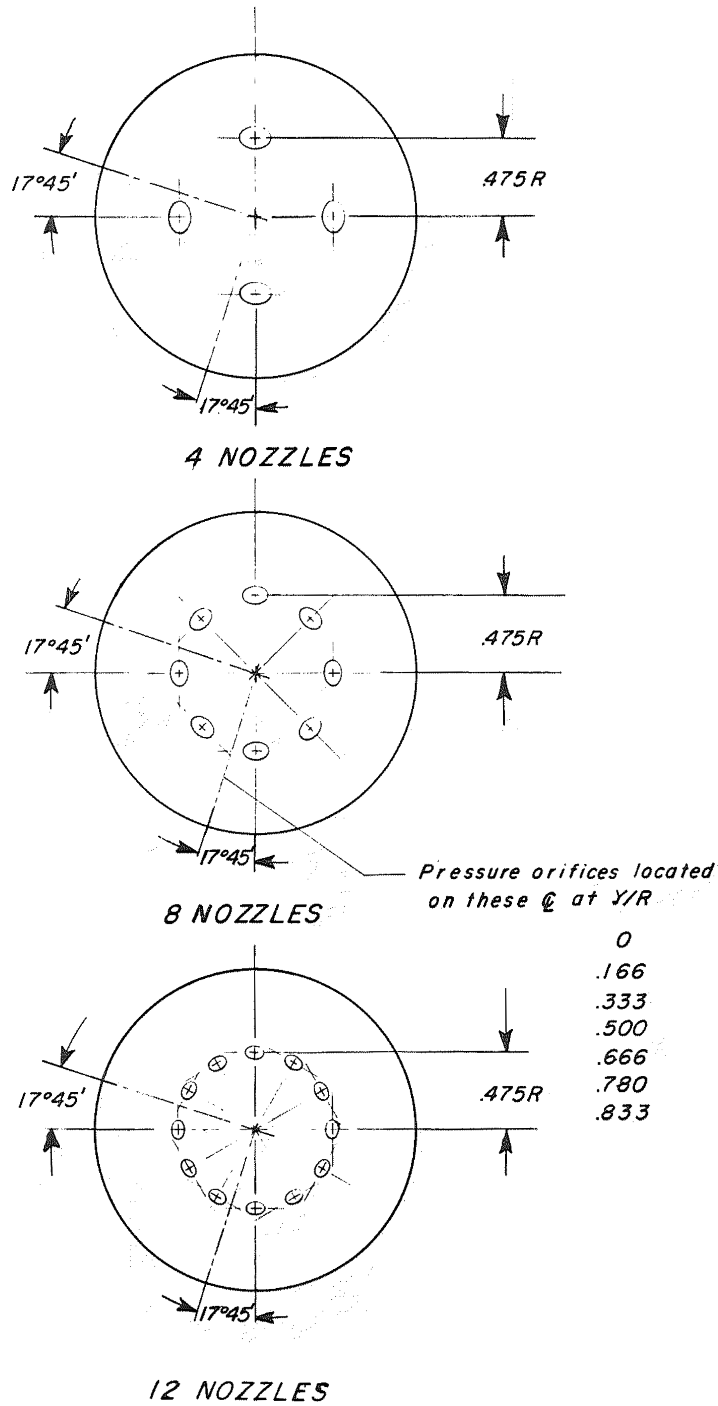


(b) Side view.



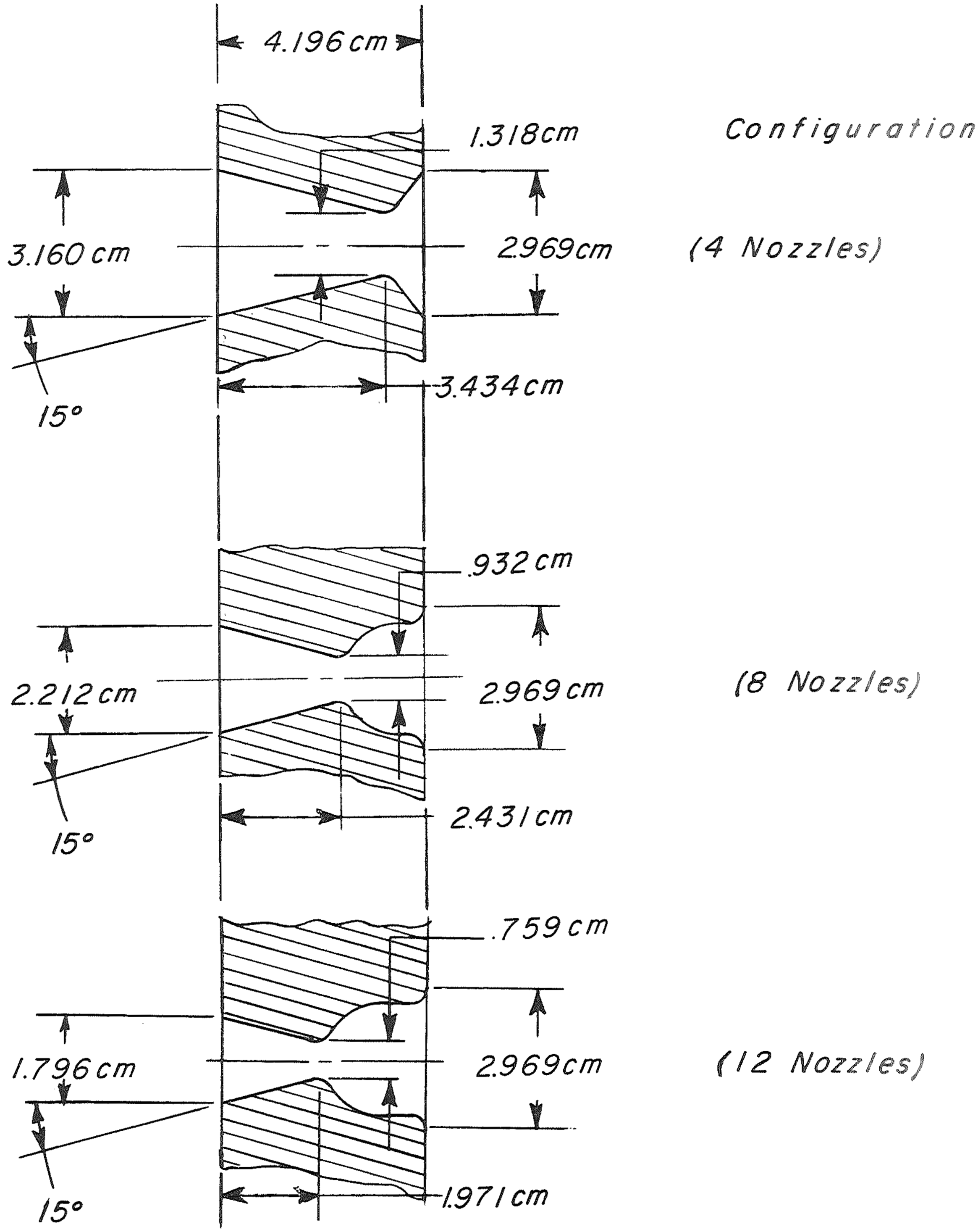
(c) Three-quarter rear view. L-71-556

Figure 1.- Concluded.



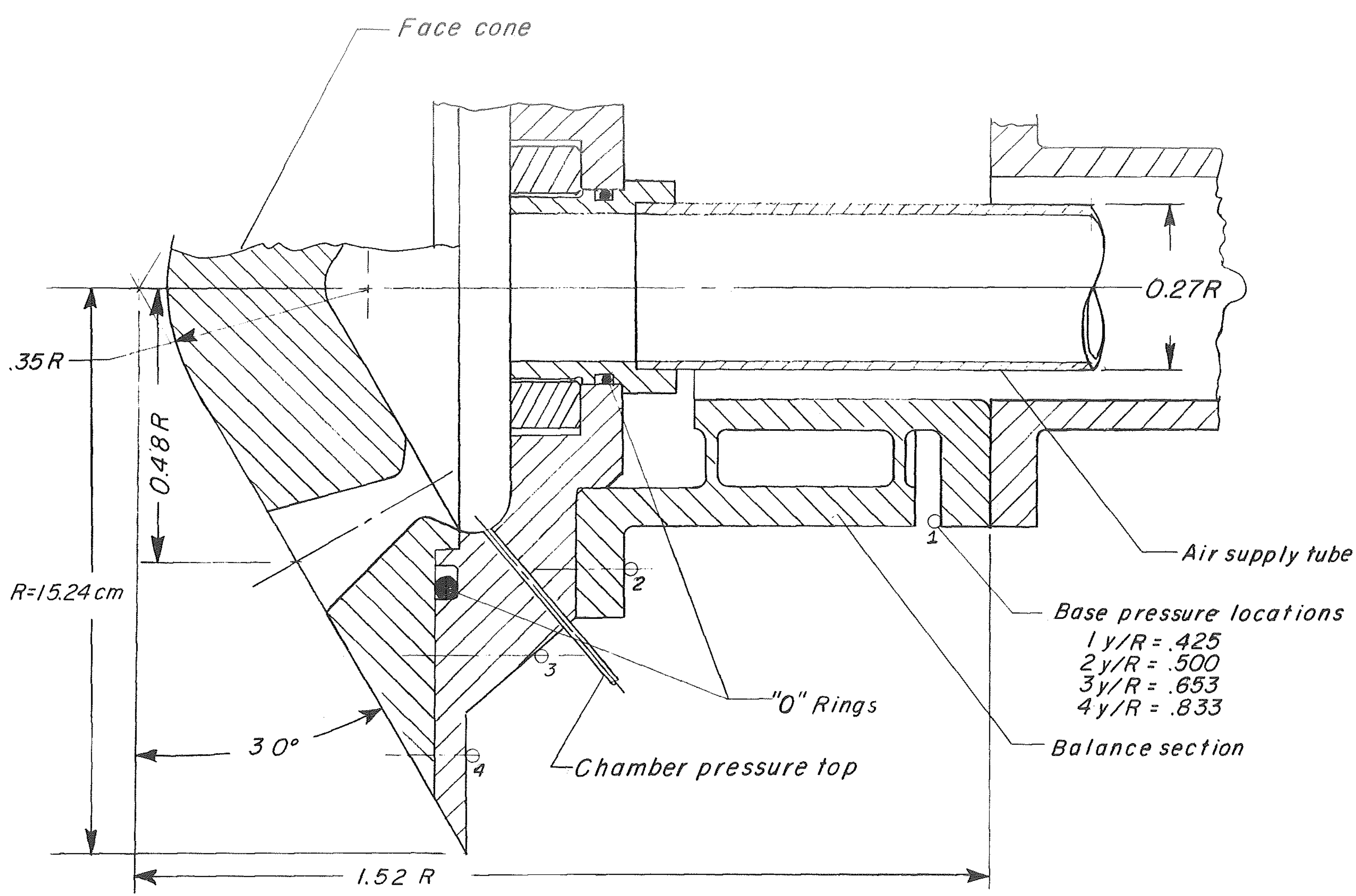
(a) Nozzle configurations.

Figure 2.- Model details.



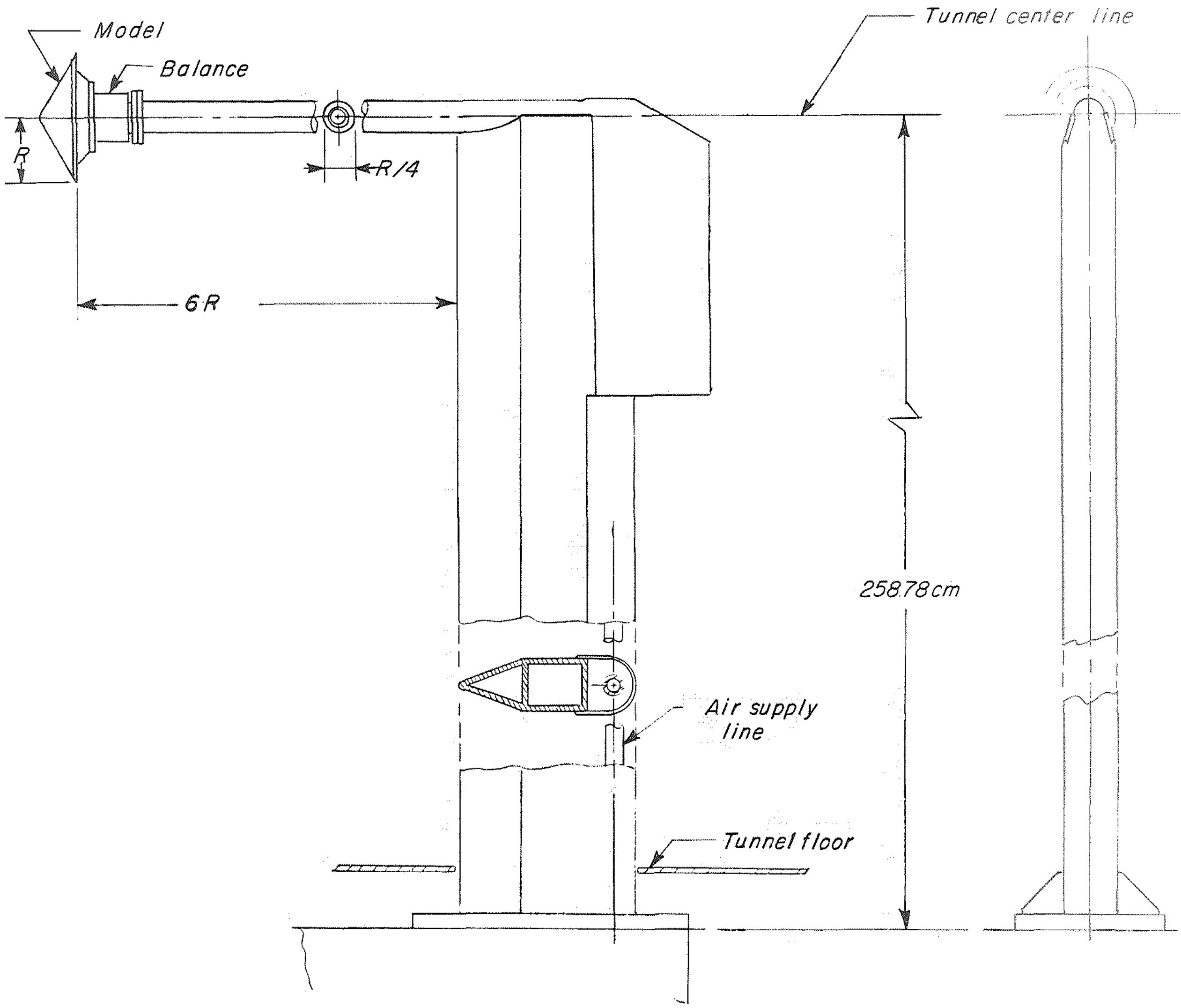
(b) Nozzle details.

Figure 2.- Continued.



(c) Model details.

Figure 2.- Continued.



(d) Assembly details.

Figure 2.- Concluded.

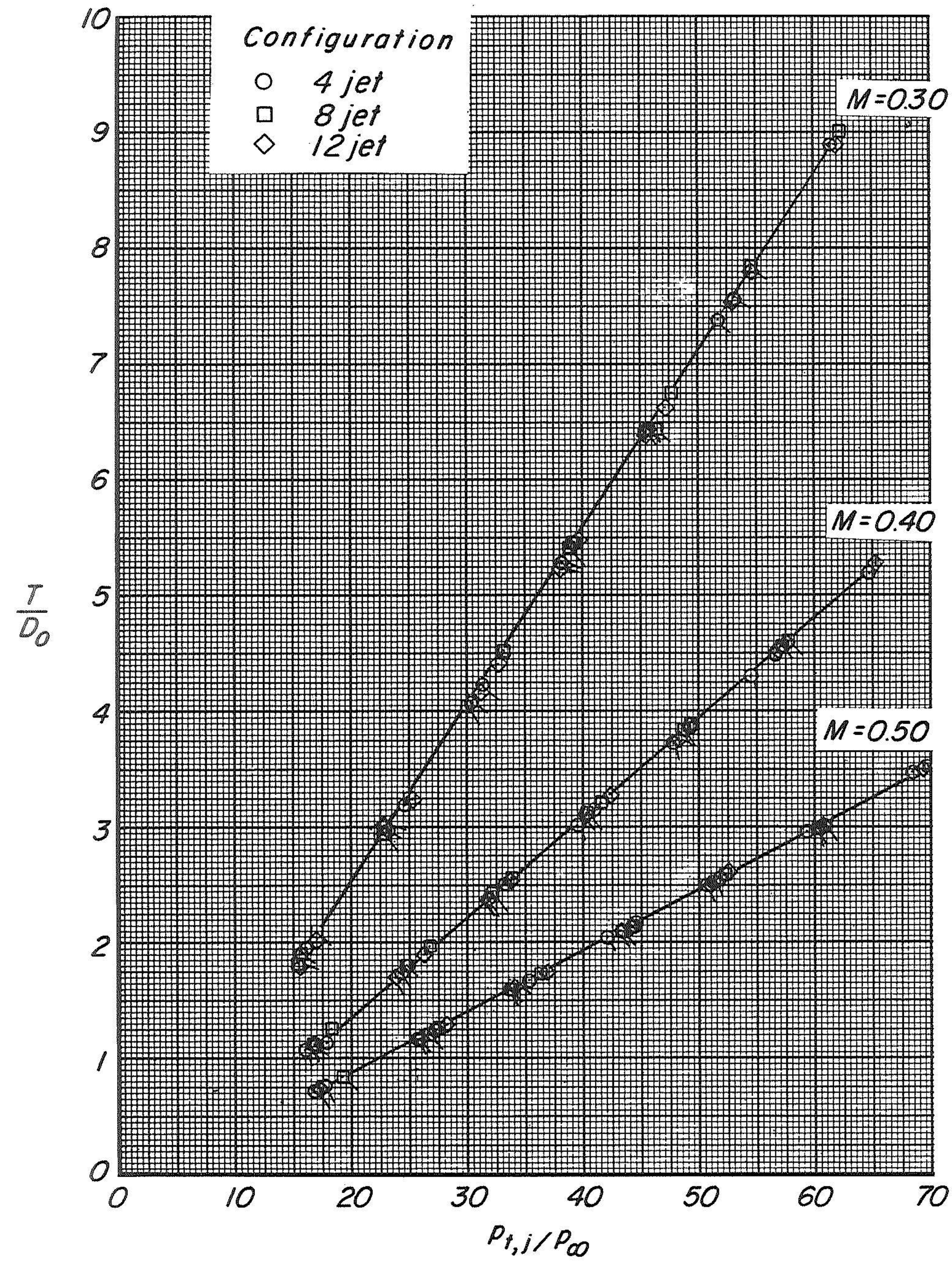
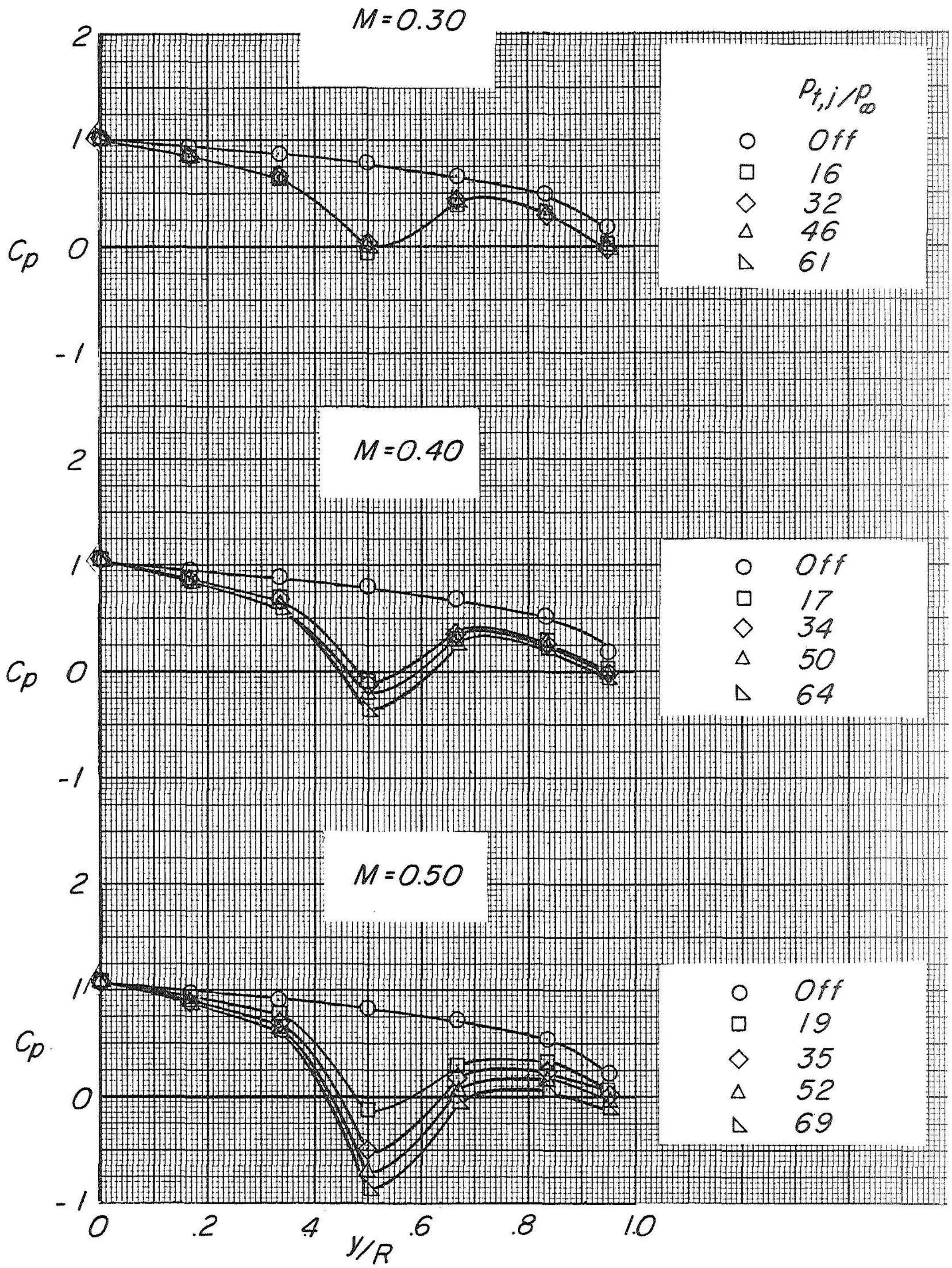
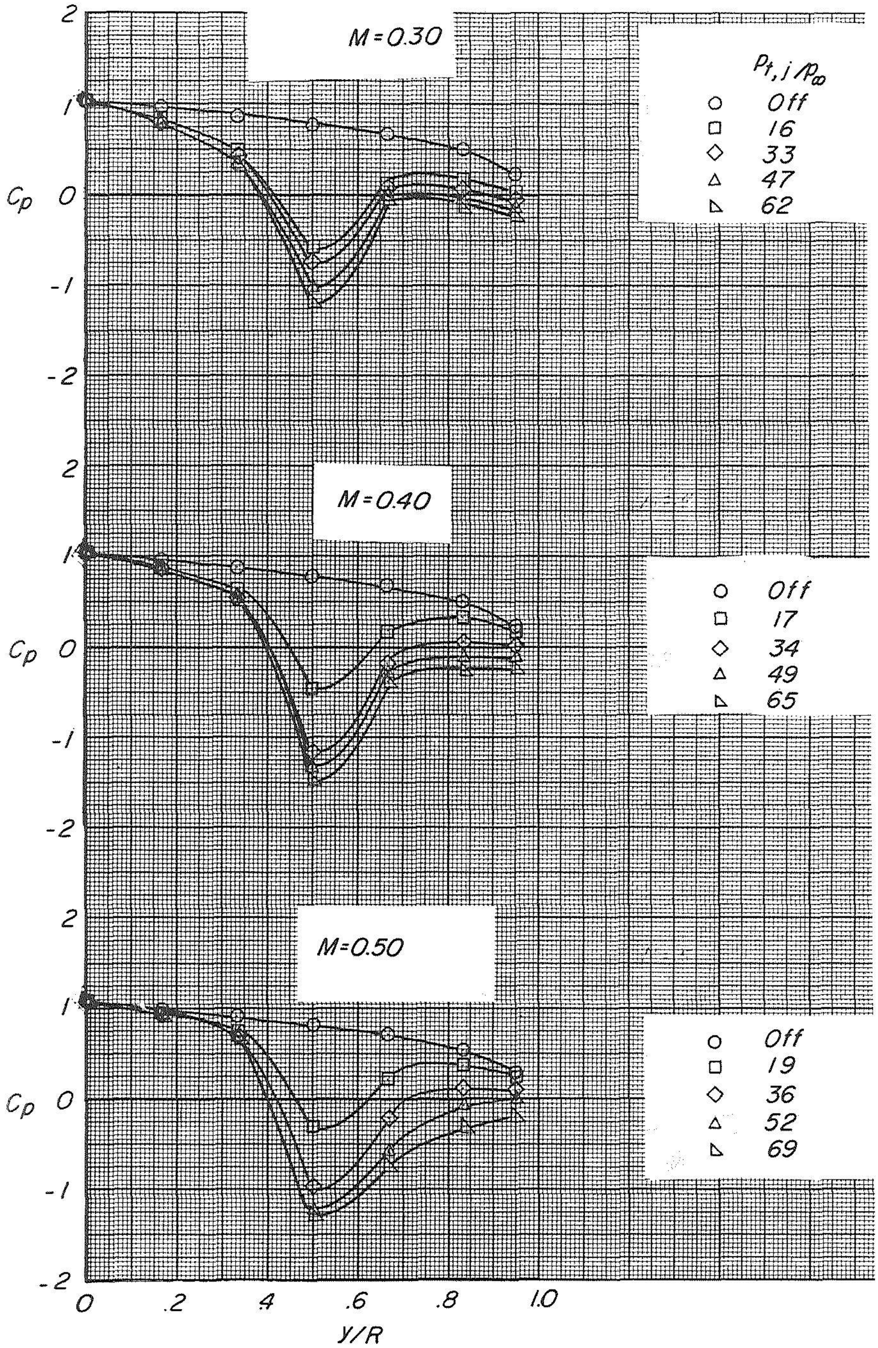


Figure 3.- Static-thrust calibration. Flagged symbols denote points obtained with descending pressure.



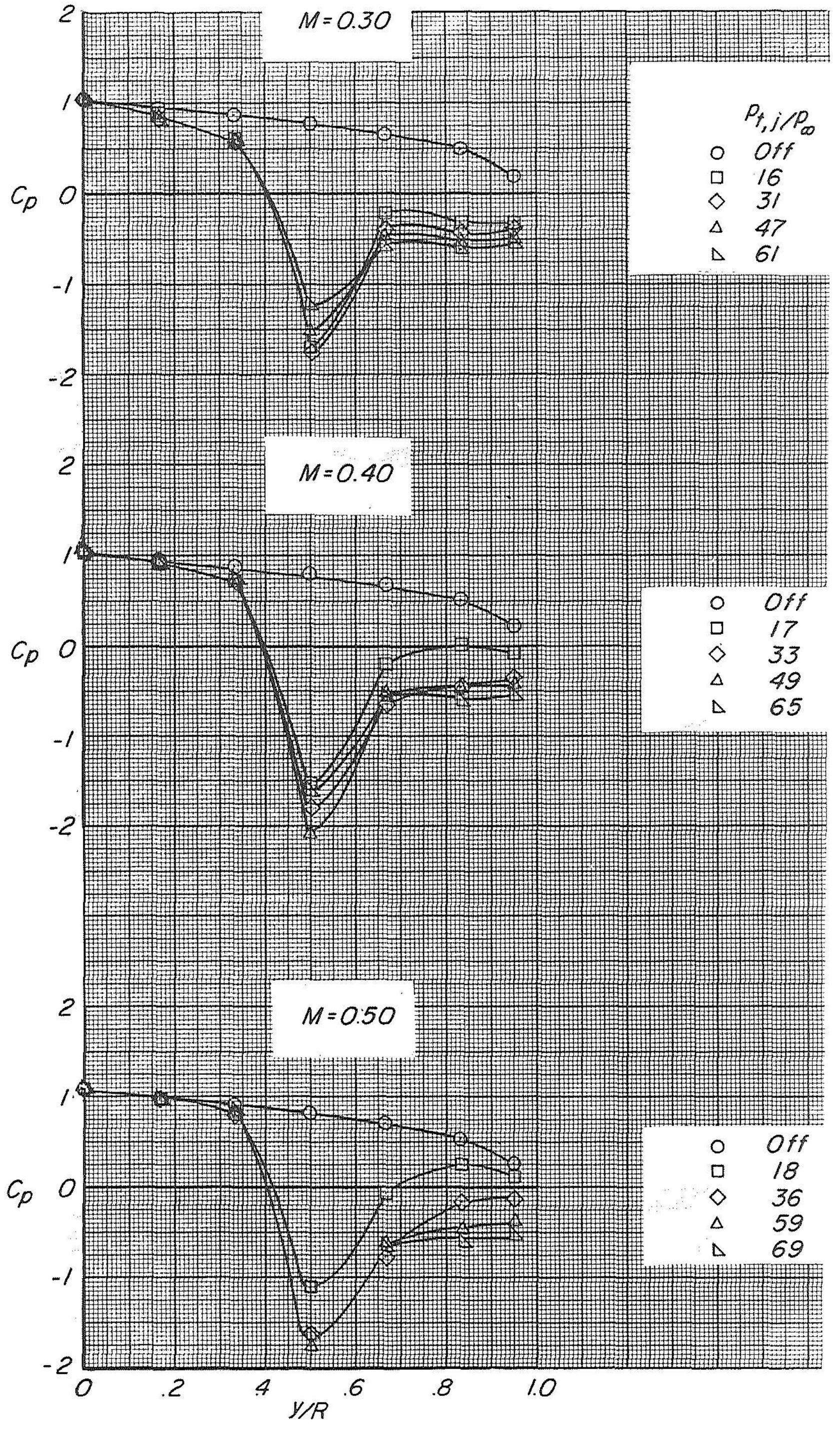
(a) 4-jet configuration.

Figure 4.- Variation of pressure over face of model.



(b) 8-jet configuration.

Figure 4.- Continued.



(c) 12-jet configuration.

Figure 4.- Concluded.

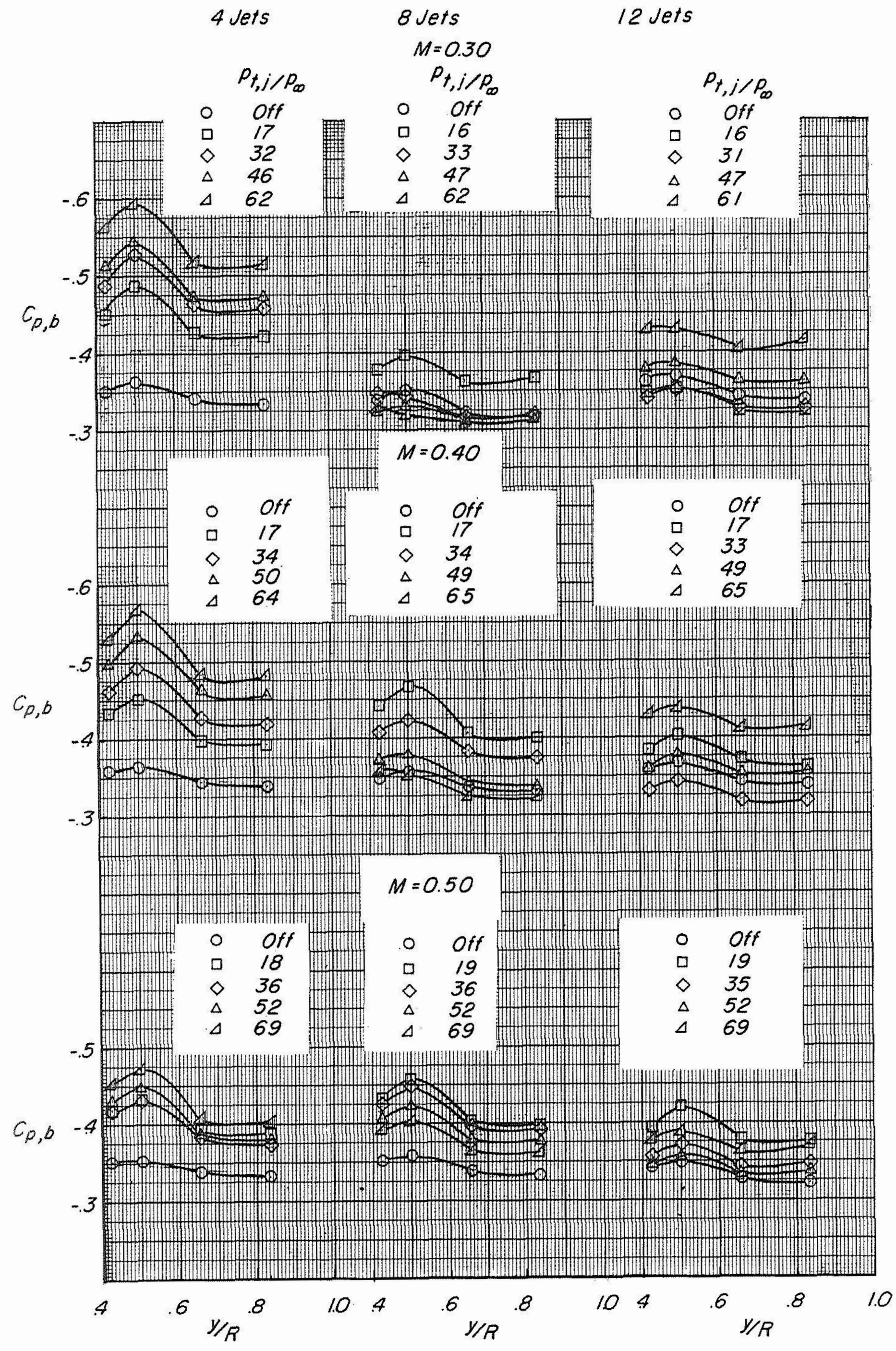
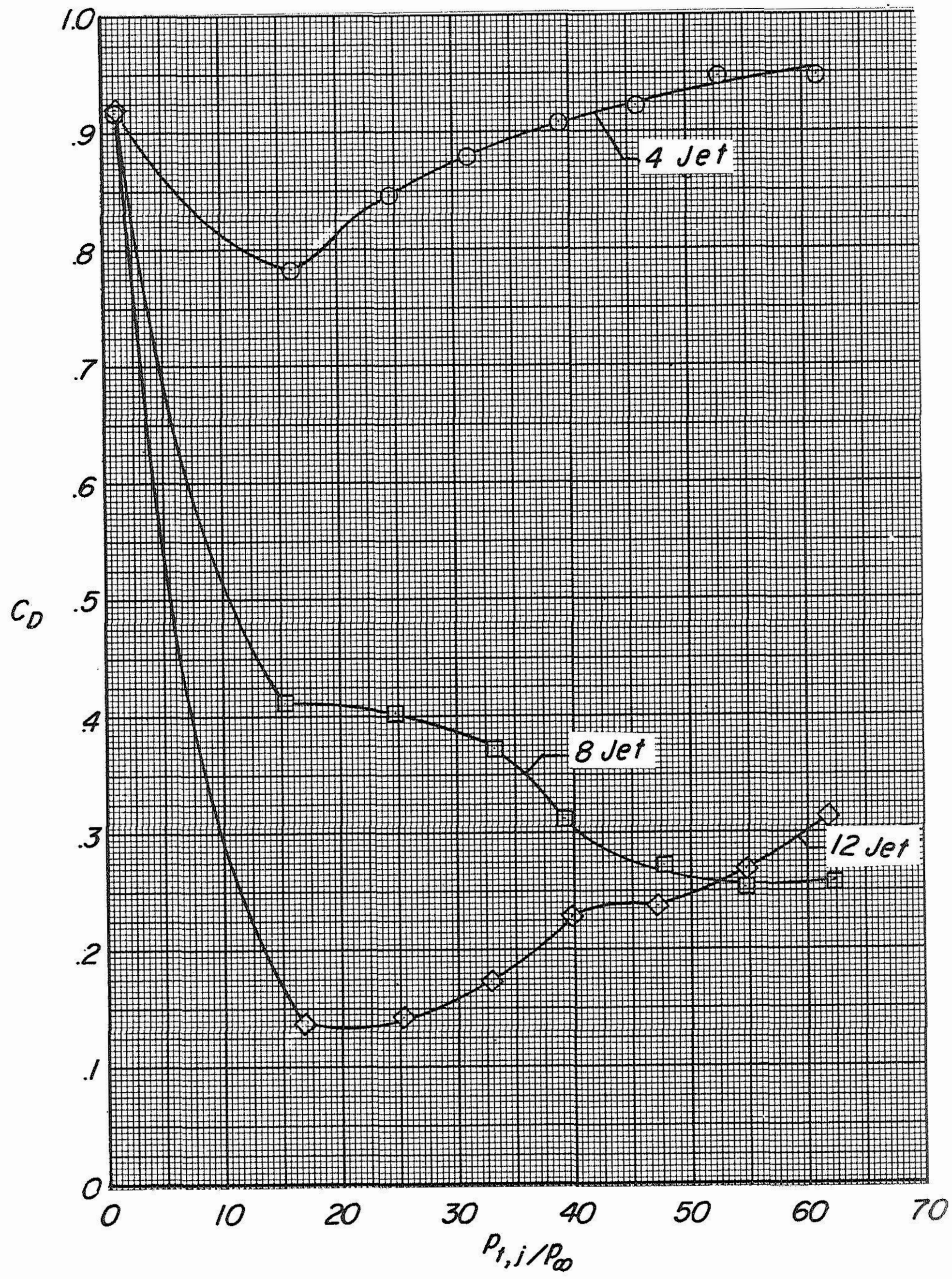
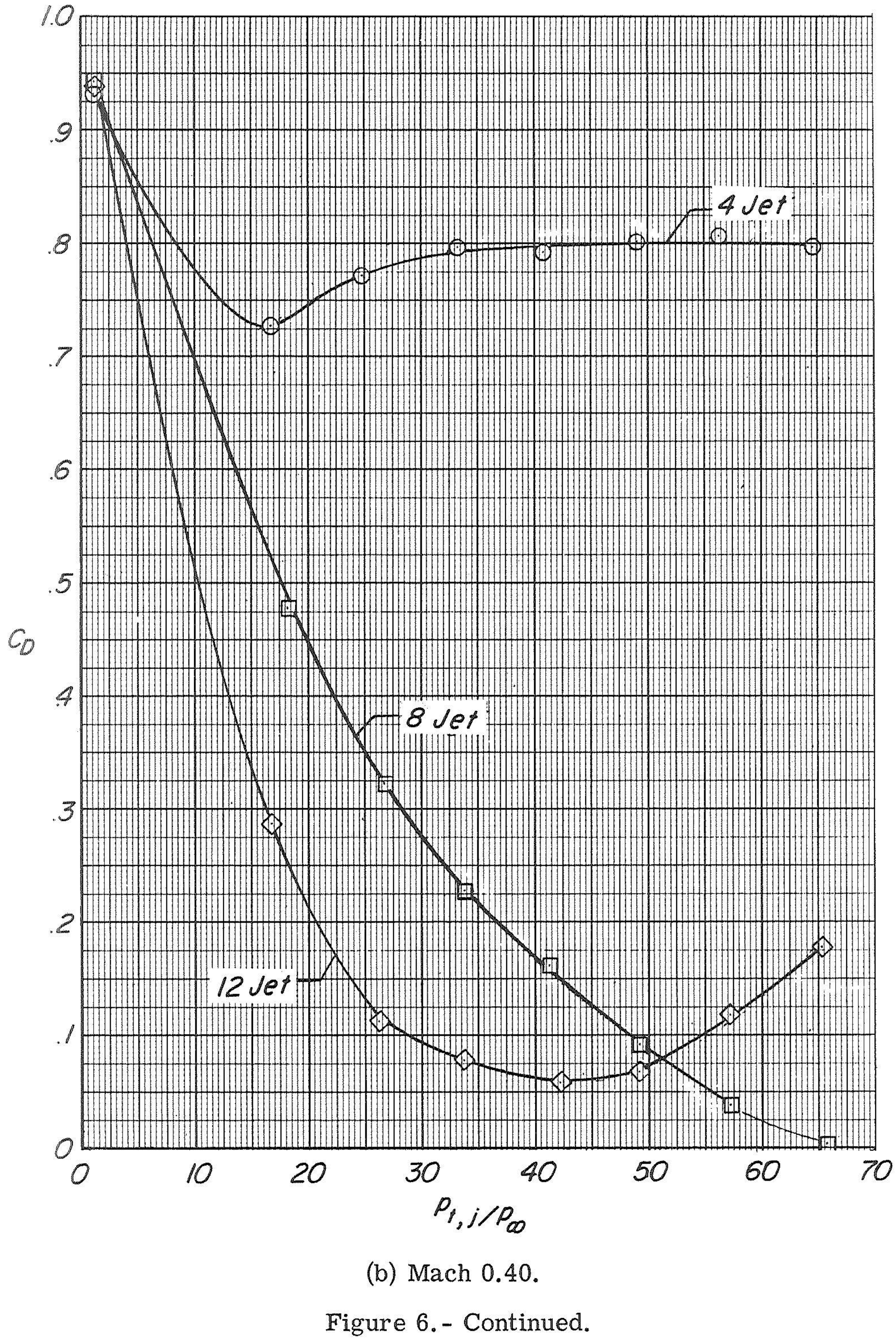


Figure 5.- Base-pressure variation.



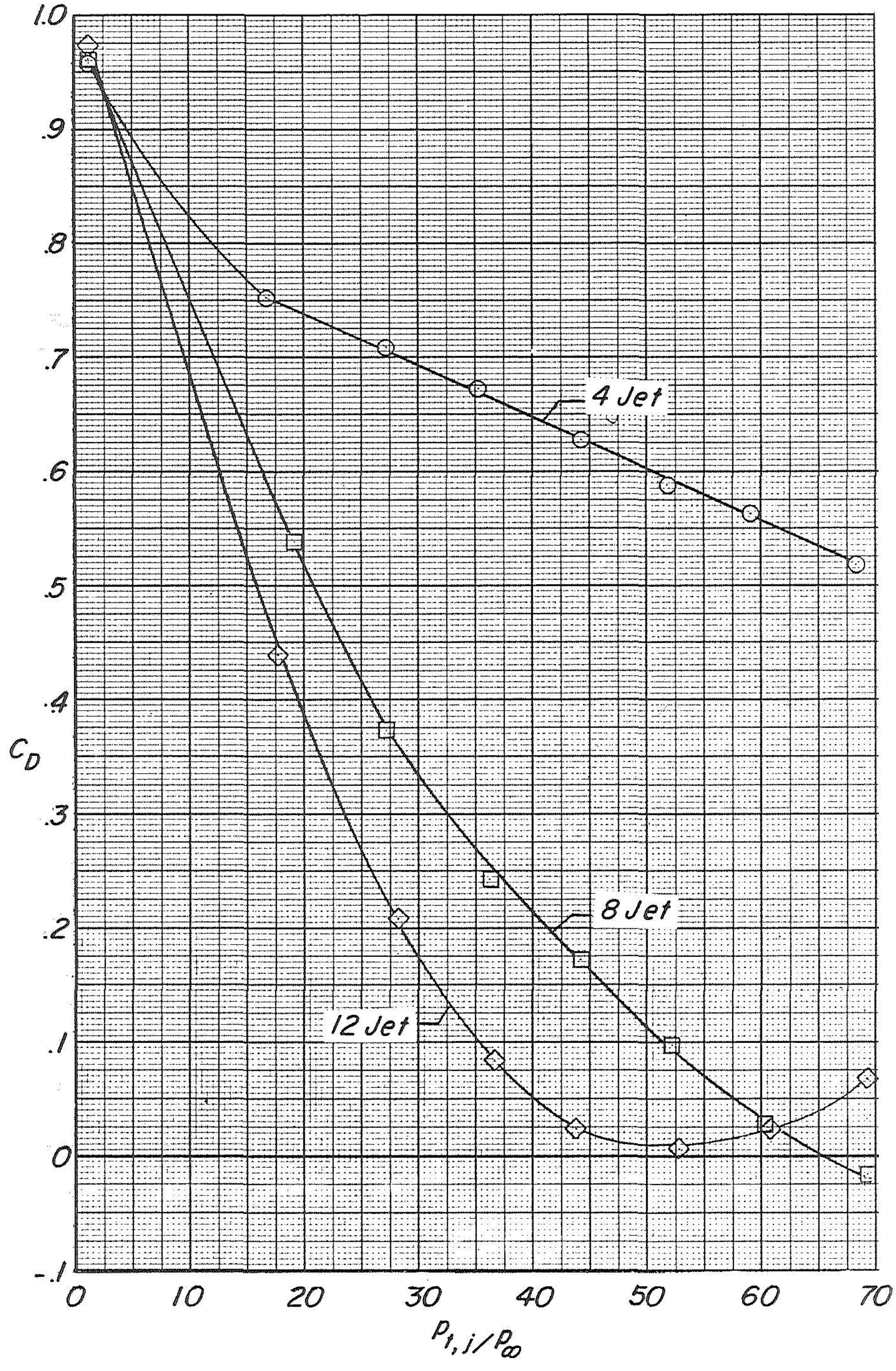
(a) Mach 0.30.

Figure 6.- Effect of jet exhaust on drag coefficient.



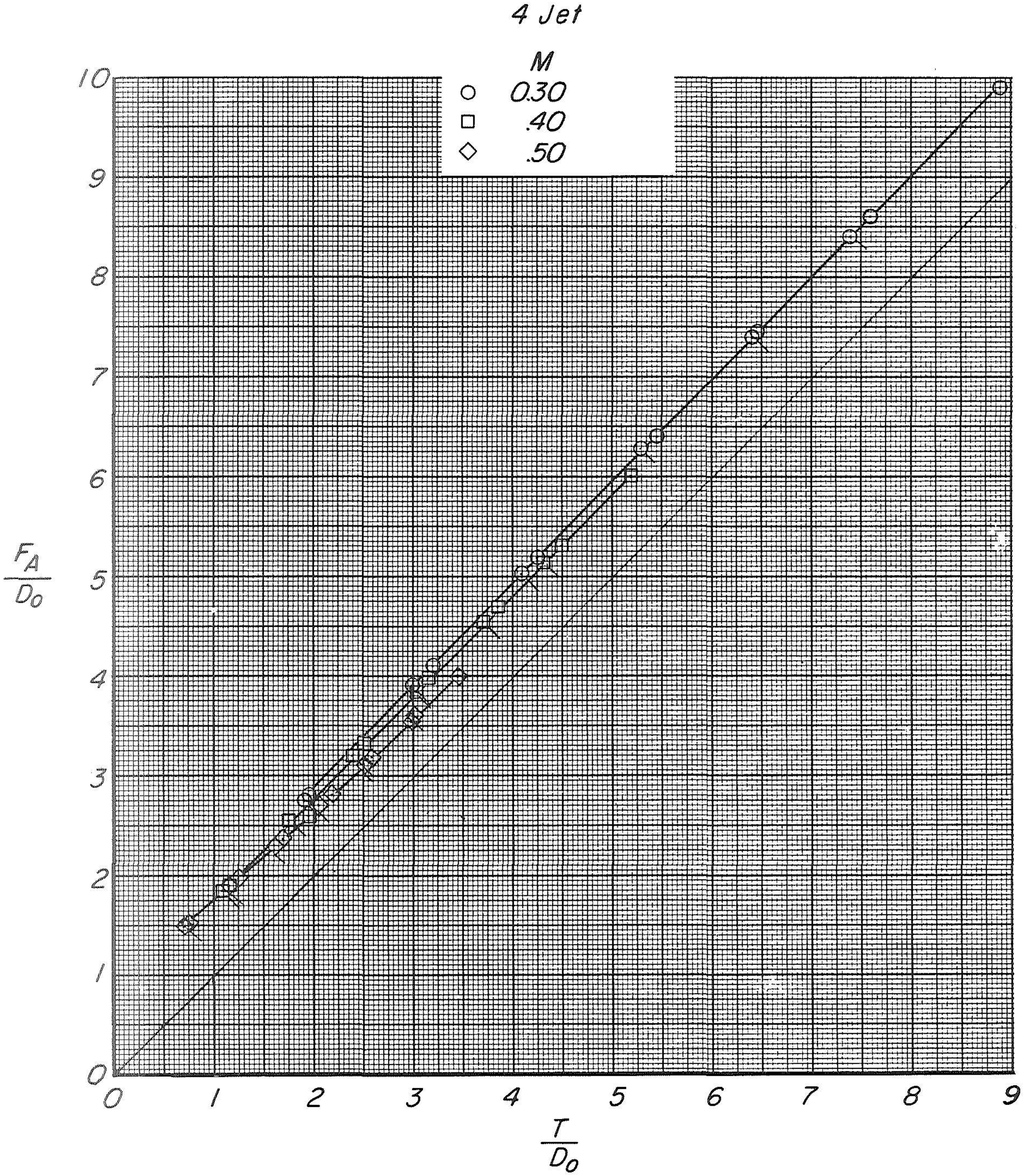
(b) Mach 0.40.

Figure 6.- Continued.



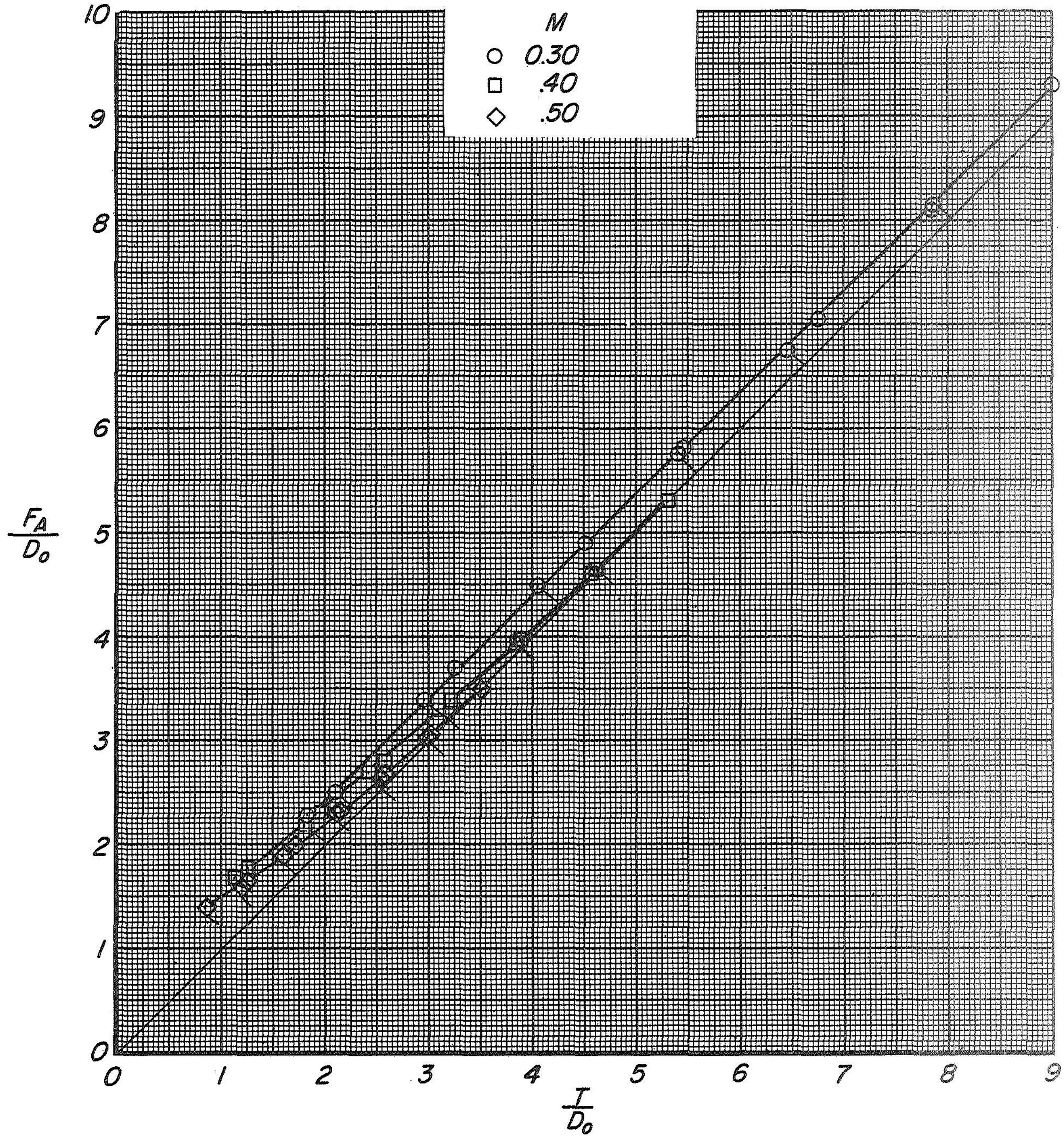
(c) Mach 0.50.

Figure 6.- Concluded.



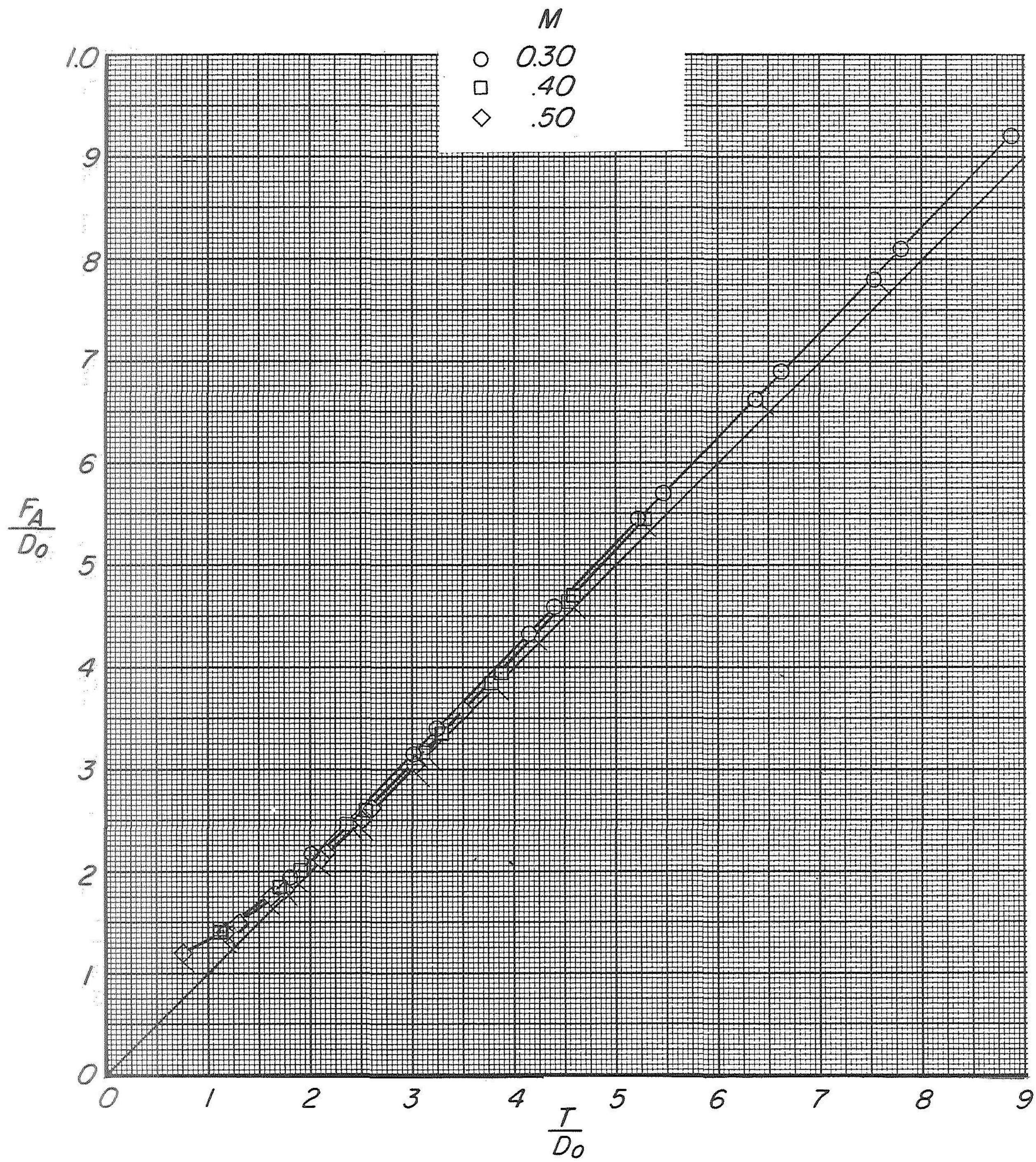
(a) 4-jet configuration.

Figure 7.- Effect of jet exhaust on total braking force.



(b) 8-jet configuration.

Figure 7.- Continued.



(c) 12-jet configuration.

Figure 7.- Concluded.

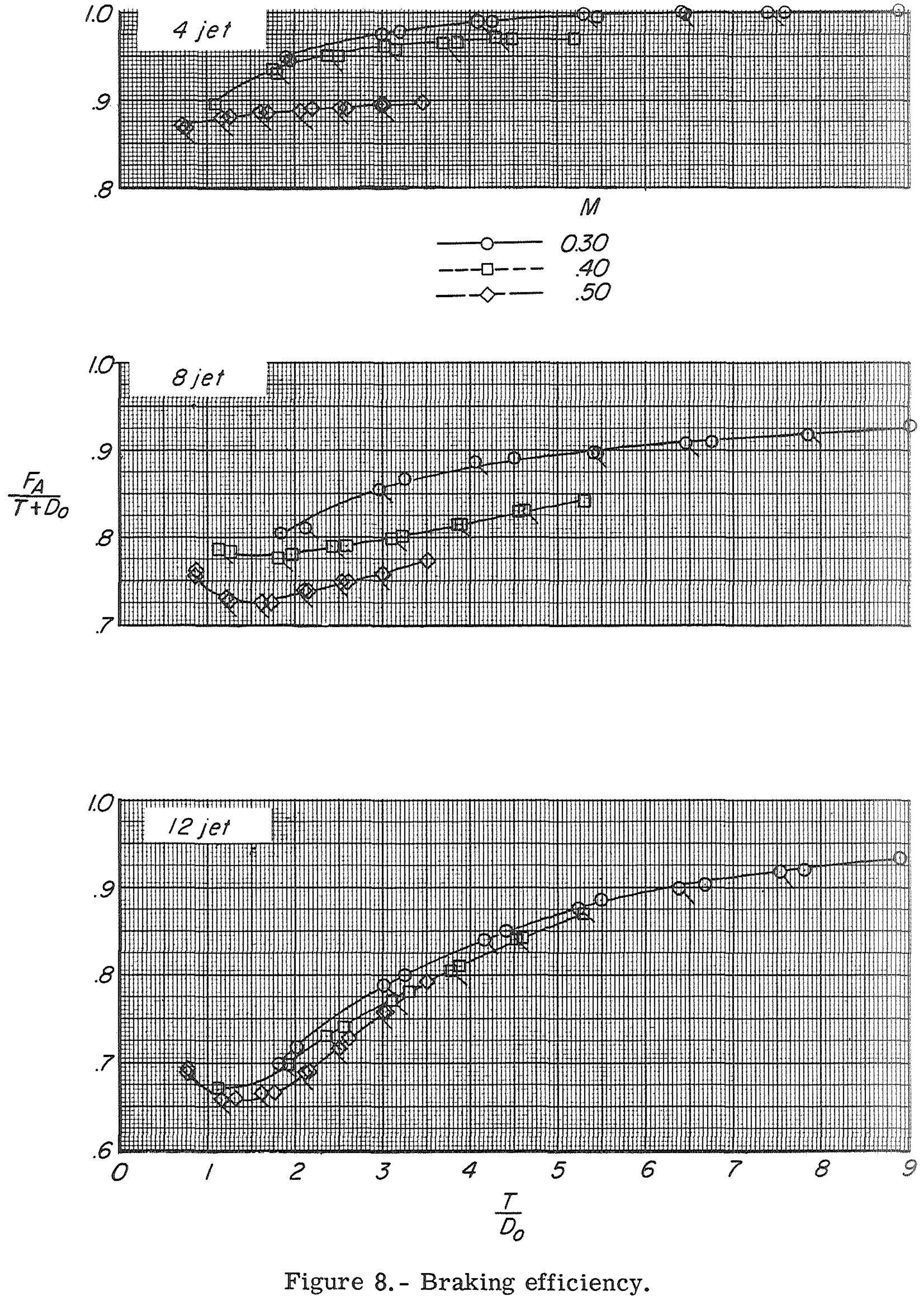


Figure 8.- Braking efficiency.

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